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MODIFICATION OF THE NEAR-IR REFLECTANCE REQUIREMENTS TEST

By
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By choosing dyes for the US Army's Woodland Battledress Uniform (BDU) colors which provide spectral reflectance values compatible with those of the major components of a verdant terrain during the day and night, the BDU blends better with the environment during the day and does not present a readily detectable monotone when viewed through a starlight scope. Thus, camouflage has been extended into the near-IR.

On occasion, dyers have had difficulty in meeting both the visual and NIR requirements. This report describes a method of acceptability testing requiring only a single (pass/fail) value. This value is obtained using an integration procedure over the wavelengths of interest instead of requiring that the reflectance values fall within a specified band. The test should make it easier for the dyed or printed material to meet the production specification requirements, and still provide the necessary reflectance properties for effective camouflage in the near-IR.

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SUMMARY

By choosing dyes for the US Army's Woodland Battledress (BDU) colors which provide spectral reflectance values compatible with those of the major components of a verdant terrain during the day and night, the BDU blends better with the environment during the day and does not present a readily detectable monotone when viewed through a starlight scope. Thus, camouflage has been extended into the near-IR (NIR).

On occasion, dyers have had difficulty in meeting both the visual and NIR requirements. This report describes a method of acceptability testing requiring only a single (pass/fail) value. This value is obtained using an integration procedure over the wavelengths of interest instead of requiring that the reflectance values fall within a specified band. The test should make it easier for the dyed or printed material to meet the production specification requirements, and still provide the necessary reflectance properties for effective camouflage in the NIR.

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Preface

This report describes a new and simpler acceptability test needed to determine whether or not near-IR criteria are met. The study was carried out by investigators from the U. S. Army Natick Research, Development and Engineering Center from October 1989 to September 1990.

Acknowledgement

The authors would like to thank Ms. T. Commerford and Mr. M. Larrivee of the U.S. Army Natick Research, Development, and Engineering Center for their advice and support during the course of this investigation.

Modification of the Near-IR

Reflectance Requirements Test

Introduction

The need for camouflage in the near-IR (NIR) has been fully discussed by Ramsley & Yeomans (1). The current reflectance qualification procedure for the Woodland Battledress Uniform requires checking 14 reflectance values in the NIR, 600 - 860 nm (2). This report describes a simplification of their reflectance qualification procedure, and evaluates recent (unclassified) advances in night vision devices.

Briefly, there is sufficient light in the night sky (moonlit or moonless) to enable objects with reflectances substantially different from the surroundings to be seen quite clearly with image intensifiers such as the AN/PVS-2B Night Vision Sight. If a soldier`s clothing has a very high or very low, and especially uniform, reflectance across the visible and NIR ranges compared to the background, he becomes an obvious target for a sniper using a starlight scope.

To avoid this situation, the dyes used to match each color must provide the required spectral matches from 400 to 900 nm, but have reflectances from 700 to 900 nm (NIR) which are substantially different from each other but still similar to various terrain elements. Thus, when the uniform is when viewed through a starlight scope, no longer presents a monotone target that is readily discernible, but, instead, appears as a patchwork of light and dark areas that blends with the surroundings.

Procedure

To provide different reflectances across the NIR, each camouflage color was assigned a bandwidth (2) in the NIR within which its reflectance spectrum should fall. Even though the bandwidth (channel) is usually greater than plus or minus 10% of the reflectance of the standard, dyers have had difficulty in obtaining formulations that meet the visual color specifications and also provide reflectances that fall entirely within the standard's NIR channel at night. Consequently, colors that trespassed the channel boundaries at 3 or fewer points were accepted, since this did not appreciably affect the NIR spectral reflectance requirements. However, a simpler method was desired that would provide a single number (pass/fail) criterion for acceptance and obviate waivered buys.

Using the integration method developed by Ramsley and Yeomans, pass/fail limits for the test were obtained empirically. Reflectance data had been collected over a period of time on a large number of nylon/cotton twill samples of the following colors: Light Green 354, 1805 samples; Dark Green 355, 1833 samples; and Brown 356, 1742 samples. These data were then used to calculate the average value of Ns for nighttime illumination, and the corresponding value of Ls, the lightness under nighttime illumination, for both moonlit and moonless conditions.

The value of Ns, the nighttime illumination using the starlight scope, is given by the following equation (1):

$$Ns = \int_{400}^{900} Ix \quad Sx \quad Rx \quad dx$$

where Ix = spectral power distribution of moonlight or night sky radiance,

Sx = spectral sensitivity of the sensor,

Rx = reflectance.

Ns is analogous to the tristimulus value, Y, and is, therefore, the correlate of lightness in the visible range. The equation for Ls is:

$$Ls = 116\ (Ns/Nw)^{1/3} - 16$$

where Nw is the integrated reflectance of a perfect white. Ls and Nw are analogous to L* and Yn respectively in the visible range. (3)

Second and third generation night vision scopes with improved sensitivities, Sx, have become available (4). The sensitivity data used for the Foreign Night Vision scope is similar to that used by Ramsley and Yeomans.

Discussion and Results

The average values found for Ns and Ls and their statistical limits are given in Table 1 for all three scopes. A detailed accounting of the NIR failures (channel violations) for all three colors examined, Light Green 354, Dark Green 355, and Brown 356, are given in Tables 2 and 3.

Table 2 gives the number of channel violations at each wavelength. Examples are: For Light Green 354, 19 samples had reflectances exceeding the upper limit at 680 nm. For Dark Green 355, the reflectance values of 30 samples were lower than allowed at 740 nm. For Brown 356, the reflectance values of 99 samples were below the lower limit of the acceptability band at

Table 1. Statistical Values for Woodland Pattern Colors

Light Green 354

Foreign Night Vision Scope

	Moonlit		Moonless	
	Ns	Ls	Ns	Ls
Mean + 3 Std Dev	20.5	52.8	27.0	59.3
Mean + 2 Std Dev	19.4	51.3	25.6	57.8
Mean	17.0	48.3	22.8	54.9
Mean - 2 Std Dev	14.7	45.3	20.1	52.0
Mean - 3 Std Dev	13.6	43.9	18.7	50.5

Second Generation Night Vision Scope

	Ns	Ls	Ns	Ls
Mean + 3 Std Dev	26.5	58.8	45.2	73.4
Mean + 2 Std Dev	25.0	57.3	42.9	71.6
Mean	22.2	54.2	38.2	68.2
Mean - 2 Std Dev	19.3	51.1	33.6	64.7
Mean - 3 Std Dev	17.8	49.5	31.2	62.9

Third Generation Night Vision Scope

	Ns	Ls	Ns	Ls
Mean + 3 Std Dev	33.2	64.6	50.7	76.8
Mean + 2 Std Dev	31.5	63.1	48.3	75.1
Mean	28.1	60.0	43.3	71.8
Mean - 2 Std Dev	24.8	56.9	38.4	68.4
Mean - 3 Std Dev	23.1	55.4	35.9	66.7

Table 1. Statistical Values for Woodland Pattern Colors, Cont'd.

Dark Green 355

Foreign Night Vision Scope

	Moonlit Ns	Moonlit Ls	Moonless Ns	Moonless Ls
Mean + 3 Std Dev	11.2	40.2	15.6	46.7
Mean + 2 Std Dev	10.5	38.9	14.8	45.4
Mean	9.2	36.2	13.0	42.7
Mean - 2 Std Dev	7.8	33.6	11.2	40.1
Mean - 3 Std Dev	7.1	32.3	10.4	38.8

Second Generation Night Vision Scope

	Ns	Ls	Ns	Ls
Mean + 3 Std Dev	14.5	45.1	26.2	58.6
Mean + 2 Std Dev	13.6	43.7	24.7	56.9
Mean	11.8	40.9	21.7	53.6
Mean - 2 Std Dev	10.1	38.1	18.6	50.3
Mean - 3 Std Dev	9.2	36.7	17.1	48.7

Third Generation Night Vision Scope

	Ns	Ls	Ns	Ls
Mean + 3 Std Dev	19.4	51.4	32.5	64.1
Mean + 2 Std Dev	18.3	50.0	30.7	62.4
Mean	16.1	47.1	27.2	59.1
Mean - 2 Std Dev	13.9	44.2	23.6	55.7
Mean - 3 Std Dev	12.8	42.8	21.8	54.1

Table 1, Statistical Values for Woodland Pattern Colors, Cont'd.

Brown 356

Foreign Night Vision Scope

	Moonlit		Moonless	
	Ns	Ls	Ns	Ls
Mean + 3 Std Dev	10.0	38.1	14.9	45.9
Mean + 2 Std Dev	9.4	36.9	14.1	44.5
Mean	8.2	34.4	12.4	41.9
Mean - 2 Std Dev	7.0	31.9	10.8	39.2
Mean - 3 Std Dev	6.4	30.6	9.9	37.8

Second Generation Night Vision Scope

	Ns	Ls	Ns	Ls
Mean + 3 Std Dev	13.8	44.3	27.6	59.9
Mean + 2 Std Dev	13.0	42.9	26.0	58.2
Mean	11.3	40.1	22.7	54.7
Mean - 2 Std Dev	9.7	37.3	19.5	51.3
Mean - 3 Std Dev	8.8	35.9	17.9	49.5

Third Generation Night Vision Scope

	Ns	Ls	Ns	Ls
Mean + 3 Std Dev	19.2	51.3	33.4	64.9
Mean + 2 Std Dev	18.1	49.8	31.6	63.2
Mean	16.0	46.9	27.9	59.7
Mean - 2 Std Dev	13.8	43.9	24.2	56.3
Mean - 3 Std Dev	12.7	42.4	22.3	54.5

Table 2. NIR Acceptability Channel Violations

Total Samples Which Exceeded the Acceptability Limit at Each Wavelength

	Nanometers													
	600	620	640	660	680	700	720	740	760	780	800	820	840	860
Light Green 354														
Too High	0	1	1	17	19	9	7	12	12	2	4	2	2	2
Too Low	0	0	0	0	0	8	5	7	1	0	0	0	0	5
Dark Green 355														
Too High	1	1	2	1	1	1	2	2	2	2	2	2	1	1
Too Low	0	0	0	0	0	0	0	30	63	89	65	57	68	72
Brown 356														
Too High	0	0	1	0	0	1	1	1	1	1	0	0	0	0
Too Low	1	1	1	0	0	1	1	2	2	18	31	42	76	99

Table 3. Total Channel Violations Per Sample

Number of Samples with N Locations Exceeding the Acceptability Limits

	N = 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Light Green 354														
Too High	12	13	2	3	4	0	2	0	0	0	0	0	0	0
Too Low	9	0	4	0	1	0	0	0	0	0	0	0	0	0
Dark Green 355														
Too High	1	0	0	0	0	0	1	0	0	0	0	0	1	0
Too Low	19	18	6	3	12	23	23	0	0	0	0	0	0	0
Brown 356														
Too High	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Too Low	27	33	15	15	13	0	0	0	0	0	0	1	0	0

860 nm. Table 3 presents the same data from another point of view. Here the total number of failures per sample are tallied. Examples are: For Dark Green 355, there were 12 samples each with a total of 5 reflectances that were too low. For Brown 356, there were 33 samples that had a total of two failures: all had reflectances that were too low. As can be seen from Table 3, there were only two samples that had more than 7 failures. These were: Dark Green 355, N = 13, too high, and Brown 356, N = 12, too low. Table 3 also shows that out of 1805 samples for Light Green 354, nine had more than 3 violations that were too high, and one sample failed because its reflectance was too low at five wavelengths. For Dark Green one sample failed because there were 7 wavelengths at which the reflectance readings were above the upper limits, and 61 samples had more than 3 reflectance values which were beneath the lower limits. Finally, for Brown 356 one sample failed because it had more than 3 violations (all were too high), and twenty-nine samples had more than 3 violations (all were too low).

The number of samples that exceeded the assigned channel boundaries at 4 or more wavelengths (and were thereby rejected), and the number that failed using statistical criteria based on the third generation night vision scope under moonless conditions are given in Table 4. The third generation scope data were used because these devices respond almost equally under moonless as well as moonlit conditions.

Table 4. Number of Sample Failures Using Channel and Statistical Criteria

Color	No. of Samples	Channel	2-Sigma	3-Sigma
Lt. Green 354	1805	10	90	6
Dk. Green 355	1833	63	92	6
Brown 356	1742	30	87	5

Apparently, the easiest color to match, and also meet the NIR requirements, was the Light Green 354, since there were only 10 samples that failed at more than three wavelengths. It is evident from Table 2, that the upper limit of the acceptability channel from 660 to 760 nm was the troublesome region for Light Green 354. For both Dark Green 355 and Brown 356, the troublesome region was the lower limit from 740 or 780 to 860 nm.

Plots of the average value of Is, the average plus and minus two standard deviations, and the average plus and minus three standard deviations, are given in Figures 1 to 3 where they are represented by an asterisk, plus sign, square, dot, and X respectively. Figure 1 compares the averages for Light Green 354 and Dark Green 355. Figure 2 compares the averages for Light Green 354 and Brown 356, and Figure 3 compares the averages for Dark Green 355 and Brown 356.

The averages for moonlit conditions are based on the assumption that the spectral power distribution of moonlight is the same as the spectral power distribution of the moonlit night sky and is equivalent to CIE source D5500 (1). The radiance of the moonless night sky, which, when normalized, appears relatively rich in infrared energy, has not been included in the moonlit calculations. This was done because the radiant energy in the visible and NIR under moonless conditions is small compared to the energy under moonlit conditions. The third generation night vision scope has zero sensitivity from 400 to 540 nm and high sensitivity in the NIR as shown in Fig. 4. A large fraction of the moonlight radiance falls into the former interval. Apparently, the trend in night vision devices is to make them relatively more sensitive in the NIR so that they can function just as well under moonless as moonlit conditions. Consequently the performance data for the third generation night vision scope were selected for testing purposes.

Under moonlit conditions the averages are less than the corresponding moonless values because the large difference in light intensity is nullified during the course of the calculations. The differences in the average Ls values among the three scopes is simply a metameric effect due to the different spectral shapes of the sources. The averages under moonlit conditions are included to show that the relationship between the averages is similar to those under moonless conditions, and for future reference if needed.

The goal of the camouflage pattern is to have the dark green and brown regions of the pattern appear about the same in the NIR, with the light green regions significantly lighter. It is apparent from Figure 1 that, for the third generation scope under moonless conditions, the mean Ls values, 71.8 for Light Green 354 and 59.1 for Dark Green 355, are sufficiently far apart to provide a good contrast when viewed using the night vision device. However, the average minus two standard deviations, 66.7, for Light Green 354, is quite close to the average plus two standard deviations, 64.1, for Dark Green 355. Although the chance that this situation will arise is quite small, nevertheless, occasionally it will happen in production. Since the troublesome region for the Light Green 354 lies in the upper region of the acceptability band (See Table 2), it appears that an increase in the average for Ls will not only make it easier to meet the NIR requirements but will also provide greater contrast. A similar situation holds for the Dark Green 355 and Brown 356. In these cases the troublesome region lies in the lower limit of the acceptability channel. Consequently a decrease in the average values of Ls for these two shades should be beneficial.

Figure 3 shows that the average Ls values for Dark Green 355 and Brown 356 are close enough to be consolidated for moonlit as well as moonless conditions and for the Foreign, Second Generation, and Third Generation night vision devices.

Conclusion

For pass/fail acceptance, the ranges given in Table 5 are recommended. They are for use with the third generation night vision scope used under moonless conditions.

Table 5. Revised Ls Values for Pass/Fail Test

	Light Green 354		Dark Green 355		Brown 356	
	Computed	Revised	Computed	Revised	Computed	Revised
Upper (+3 sigma)	76.8	78.0	64.1	63.0	64.9	63.0
Average	71.8	73.0	59.1	58.0	59.7	58.0
Lower (-3 sigma)	66.7	68.0	54.1	53.0	54.5	53.0

The revised Ls values for Brown 356 were set equal to the revised Ls va for Dark Green 355.

This document reports research undertaken at the US Army Natick Research, Development and Engineering Center and has been assigned No. NATICK/TR-91/[illegible] in the series of reports approved for publication.

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APPENDIX

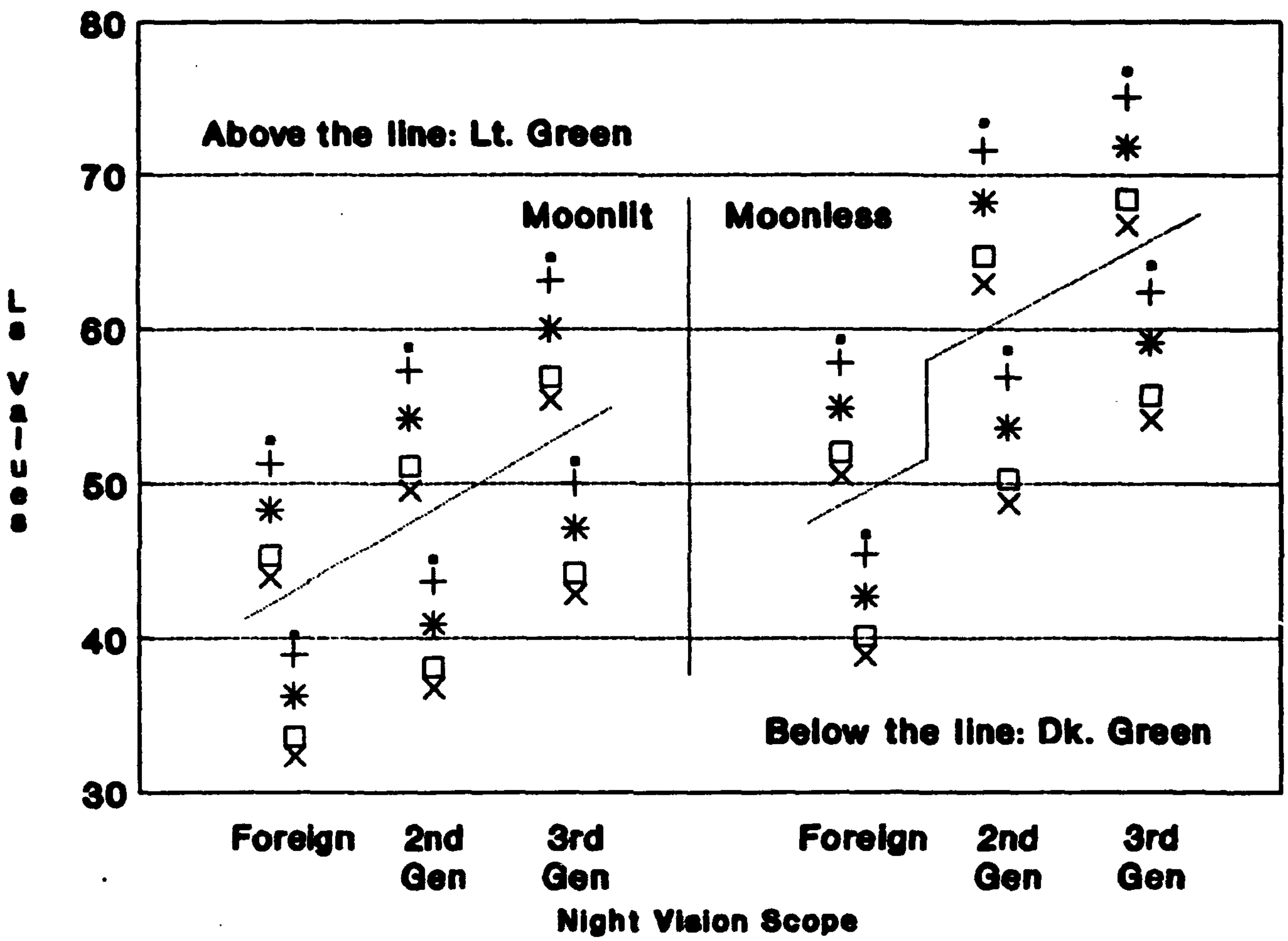

Fig. 1. Lt. Green 354 vs. Dk. Green 355

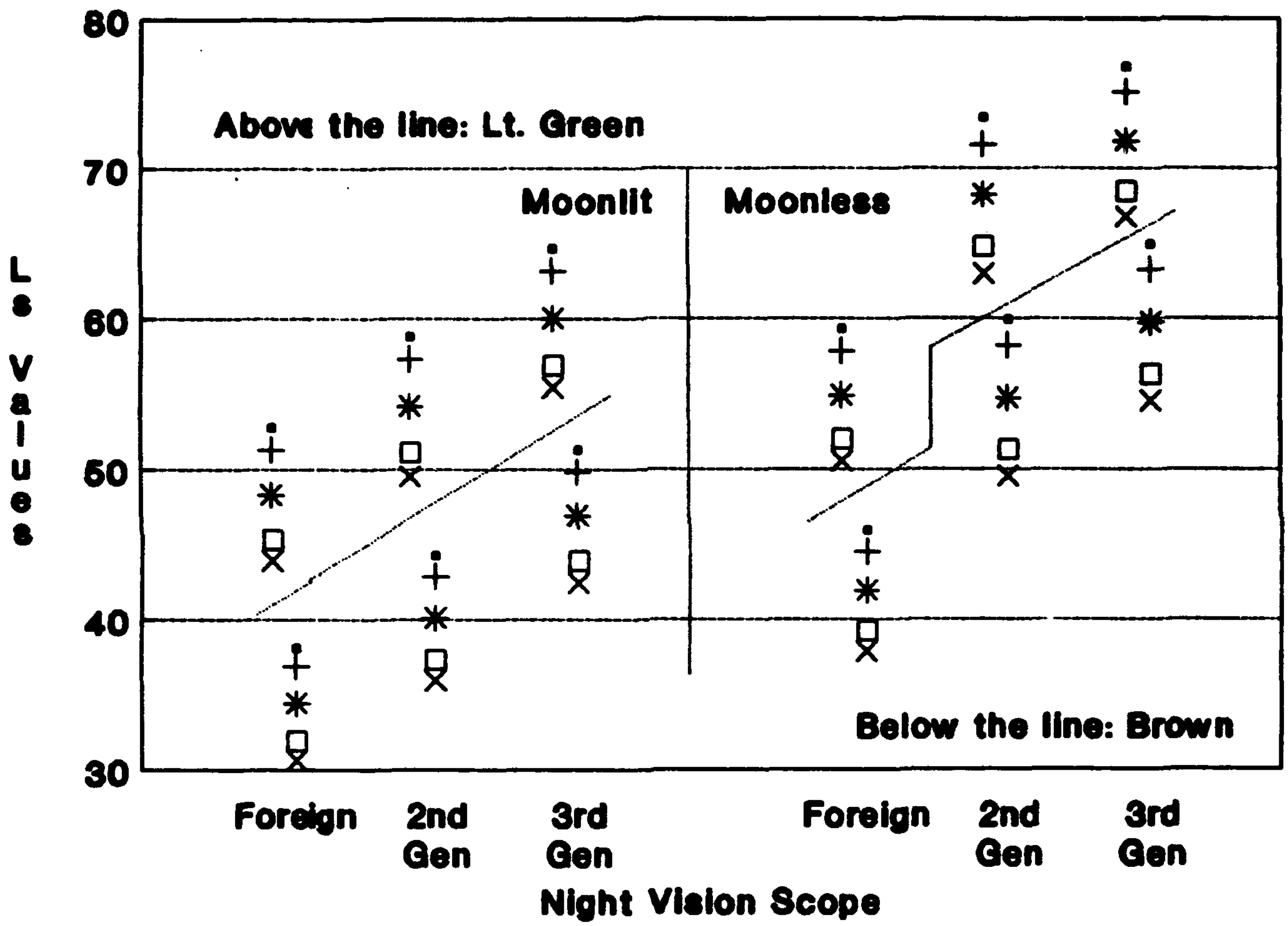

Fig. 2. Lt. Green 354 vs. Brown 356

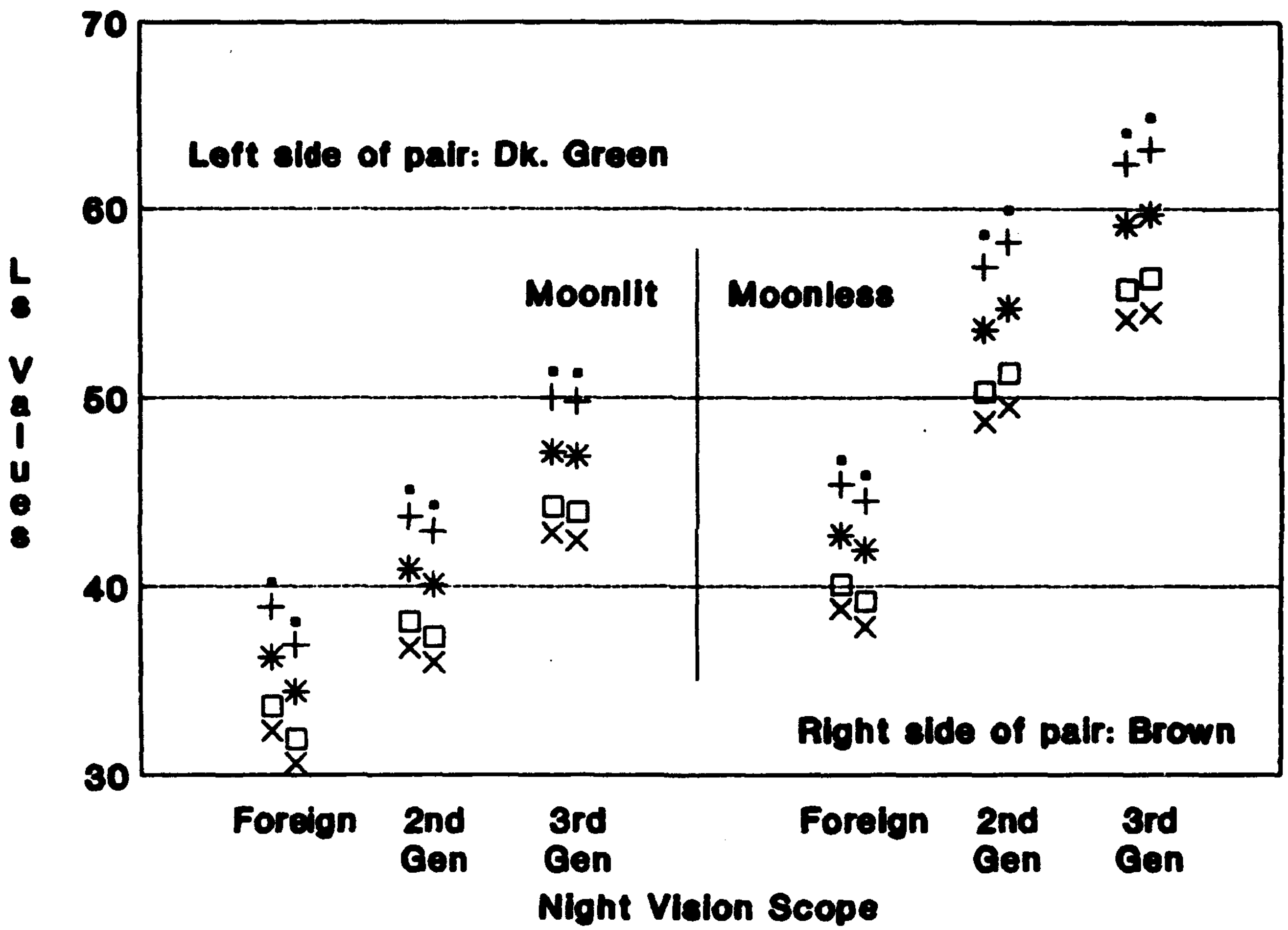

Fig. 3. Dk. Green 355 vs. Brown 356

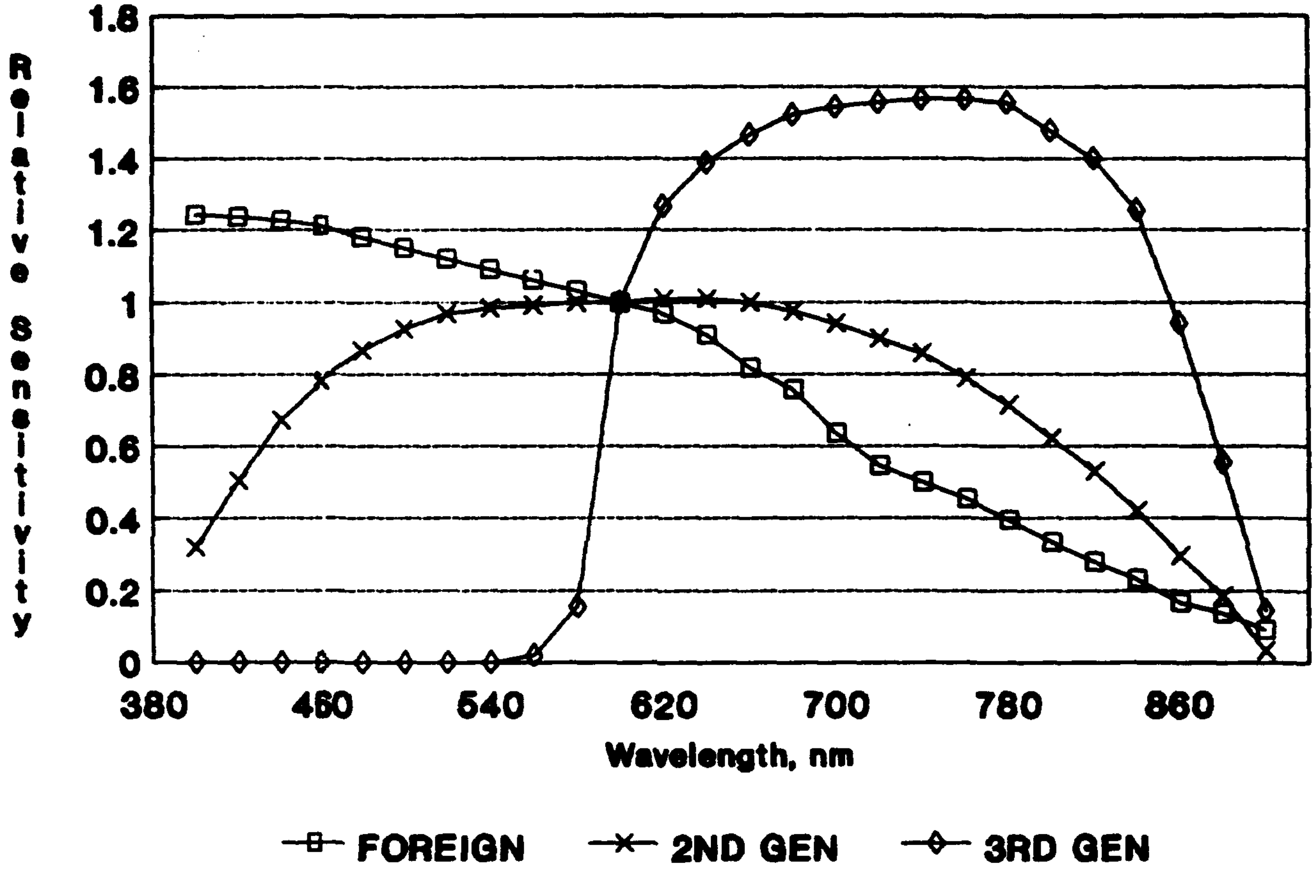

Fig. 4. Night Vision Scope Sensitivities Normalized at 600 nm